Use of ICRU-37/NBS Radiative Stopping Powers in the EGS4 System.

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Abstract

An option has been added to the PEGS4 code in the EGS4 System for the Monte Carlo simulation of radiation transport. This option allows the user to normalize the bremsstrahlung cross sections used in the code so that PEGS4 gives the same radiative stopping power for electrons as given in ICRU Report 37. The bremsstrahlung cross sections for positrons are still treated as equal to those for electrons. The data required for the new option were obtained using Stephen Seltzer's code, ESPA, which generated the ICRU stopping powers. Explicit renormalization factors were calculated for 14 elements. Interpolation of these factors to all other elements was found to produce radiative stopping powers within 1% of the ESPA radiative stopping powers for all electron energies between 10 keV and 10 GeV. These improvements can lead to significant changes in the bremsstrahlung cross sections for particle energies below 50 MeV.

1 Introduction

The EGS4 system of codes does Monte Carlo simulations of the radiation transport of electrons and photons in any material[1]. Part of the system is a stand alone code called PEGS4 which creates the necessary electron and photon data sets for use by EGS4 when doing the simulation. One important set of data is the radiative stopping power for electrons or positrons. This is calculated as the integral of the bremsstrahlung cross section differential in the emitted photon energy, for emitted photons below the production threshold, AP. For AP greater than the electron energy, this is just the unrestricted radiative stopping power for the electron.

The bremsstrahlung cross section in PEGS4 is given by the standard Bethe-Heitler cross section. Above 50 MeV, a theoretical relativistic coulomb correction to the cross section is used. Below 50 MeV the coulomb correction is replaced by an empirical correction, based on very sketchy data in Koch and Motz [2]. Data for 5 values of Z at 13 energies are used to deduce the correction factor, referred to as APRIM, by using linear interpolation in the energy and Z values. These correction factors are very crude (see e.g. pages 30, 31 in the EGS4 documentation [1]). The purpose of this report is to describe an upgrade to PEGS4 which replaces these old APRIM values by a much more extensive set that is based on the radiative stopping powers in the latest ICRU Report 37 [3] on electron stopping powers. These new APRIM values cause the radiative stopping powers to match those in ICRU Report 37. This means that the mean energy loss to photons is equal to that in ICRU37, but it does not mean that the bremsstrahlung cross sections are the same as those given by Seltzer and Berger [5,6] since they use different differential cross sections. That is, we normalize the integral of the energy weighted differential cross sections, not the cross sections themselves.

The work described here affects only the total bremsstrahlung cross section and has no effect on the relative bremsstrahlung cross section differential in photon energy for a fixed electron energy. This means that for thin targets, the new data set may produce a different number of photons, but the same photon energy spectrum will be produced. For a thick target, to the extent that the relative production at different energies may change, the spectrum may change as well.

2 Changes to PEGS4

All changes have been implemented so that a standard input file, as defined in the EGS4 documentation[1], will produce the same results as in the original version of PEGS4. To invoke the new option, the following must be done:

- In the input file, in the ELEM, MIXT or COMP options, set a new flag called IAPRIM to have a value of 1. This instructs PEGS4 to use the new values of APRIM. If unassigned, or assigned another value, the old version of PEGS4 is used.
- Assign to FORTRAN unit 22, the input file with the new APRIM values. This is part of the upgrade package. For completeness, it is listed in Appendix B.
- Run PEGS4

The output data file from PEGS4 will have the same format as in the original (with some minor additions on the second line which do *not* affect EGS4). The only real difference is that the unresticted radiative stopping powers for electrons (but not positrons) will be the same as those in ICRU Report 37.

Appendix A presents a differences comparison showing all the changes made in PEGS4 to implement these changes. Most of the changes occur in routine APRIME.

3 Data Sets from EPSTAR/ICRU 37

What spurred this work was the availability of the PC-based EPSTAR/ESPA programs written by Steven Seltzer of NBS[4]. These programs can generate the entire data base available in ICRU Report 37 [3] or alternatively Berger and Seltzer (1983) [5] (they are the programs which generated the data base). We have run these codes and obtained tables of the total radiative stopping powers as a function of energy for all elements.

4 Determination of New APRIM Values.

APRIM is a multiplicative factor which multiplies the bremsstrahlung cross section. It is a function of Z and electron energy, but not the emitted photon energy. Therefore, it is also a simple multiplicative factor for the unrestricted radiative stopping power. Using the IUNRST = 5 option in PEGS4, one gets the unrestricted radiative stopping power for electrons and positrons instead of the restricted stopping power (this option is an undocumented part of the original PEGS4 program). We first modified the FUNCTION APRIM routine in PEGS4 to always return APRIM=1.00 instead of the Koch and Motz values.

For any element for which we wanted new APRIM correction factors, we ran the modified PEGS4 code to produce a table of electron unrestricted radiative stopping powers at the same energy grid used by the ESPA code (spanning 1 keV to 10 GeV). At each energy we divided these into the radiative stopping power as given by the program ESPA (i.e. the ICRU Report 37 value) and then used the ratio as the new APRIM as a function of energy for this element. This guaranteed that for this Z, PEGS4 would reproduce the ICRU 37 values of the radiative stopping power.

Two comments are in order. The first concerns the size of the changes. Figures 1 and 2 show the old and new radiative stopping powers and their ratio, for carbon and uranium as a function of electron energy. The ratio is very small for low energies and approaches unity to within 1 or 2% for high energies when Z is greater than 10, although it can be as much as 5% for low-Z materials, even at high energies. For low-Z materials the old data are high by up to 40% near 1 MeV. In other words, the original cross sections in PEGS4 are very low at low energies, very nearly the same as those of the ICRU at higher energies, and somewhat high for low-Z materials near the 1 MeV region. This is shown more clearly by comparing Figure 5, which shows the old correction factors to Figures 3 and 4 which show plots of the new correction factors as a function of Z for a variety of energies.

The second comment concerns the discontinuity in APRIM at 50 MeV. This is required because PEGS4 turns on the relativistic coulomb correction factor at 50 MeV. To keep the physical cross sections smoothly matching the ICRU values near 50 MeV, there is a corresponding discontinuity in the APRIM values.

We created APRIM data sets for an ever expanding set of elements, spanning Z=1 to 100, until we had a set of APRIM values which could be interpolated

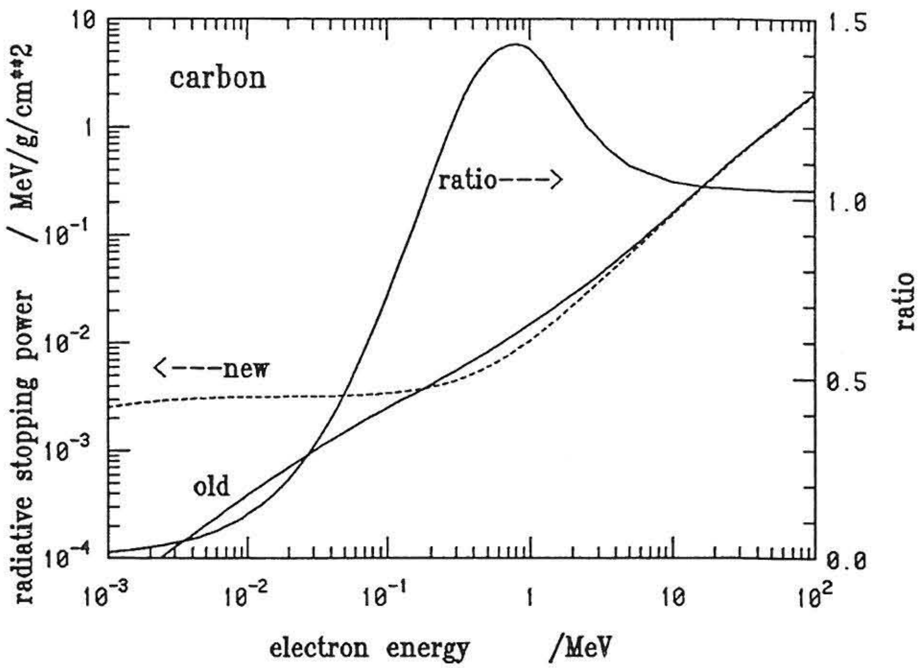

Figure 1: Comparison for carbon of old and new radiative stopping powers and the ratio of old to new.

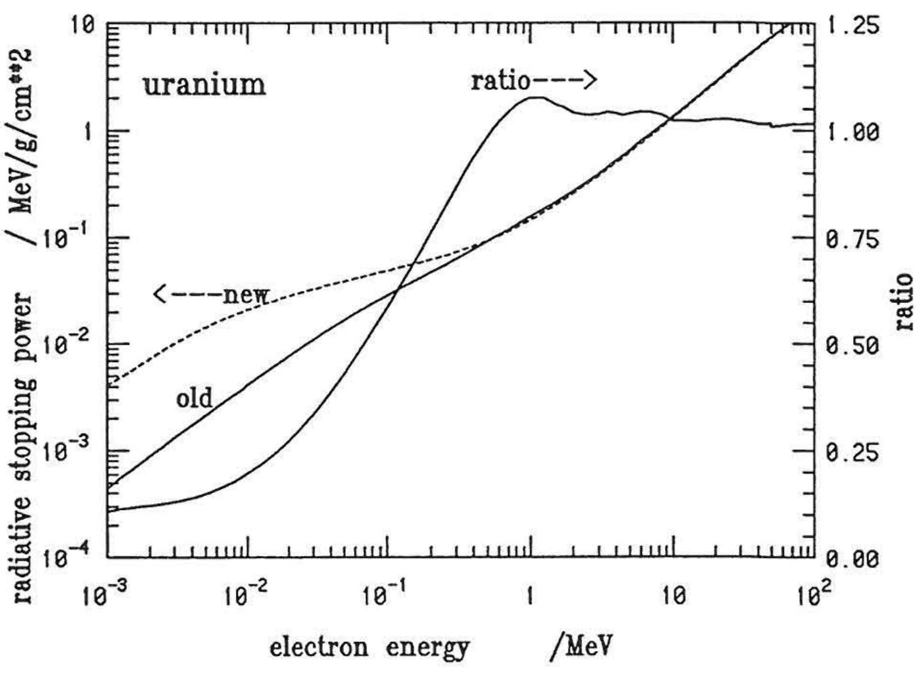

Figure 2: Comparison for uranium of old and new radiative stopping powers and the ratio of old to new.

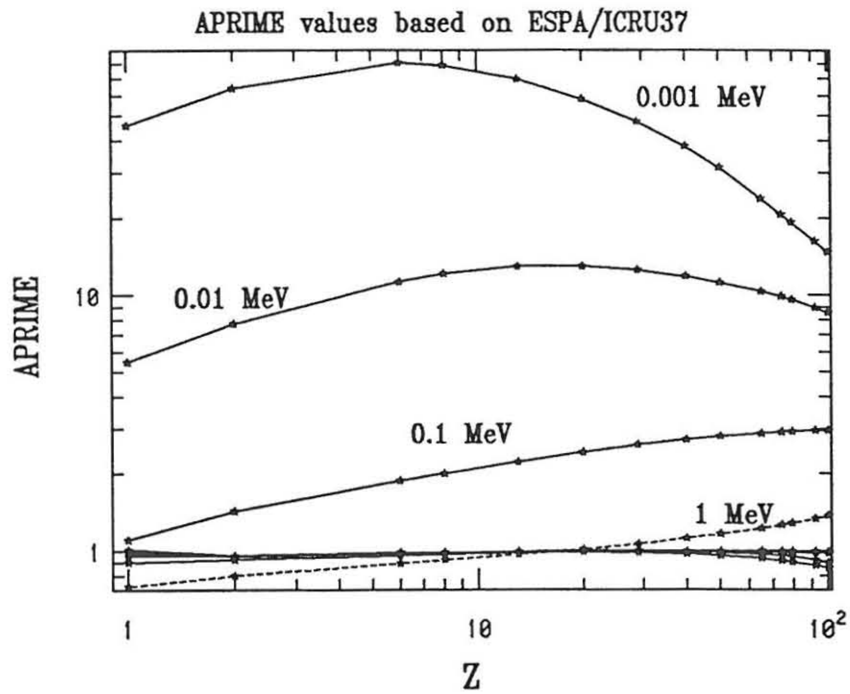

Figure 3: Values of APRIM used to give ICRU37 radiative stopping powers in PEGS4. Other values are interpolated linearly in log Z which causes minor problems at very low energies only.

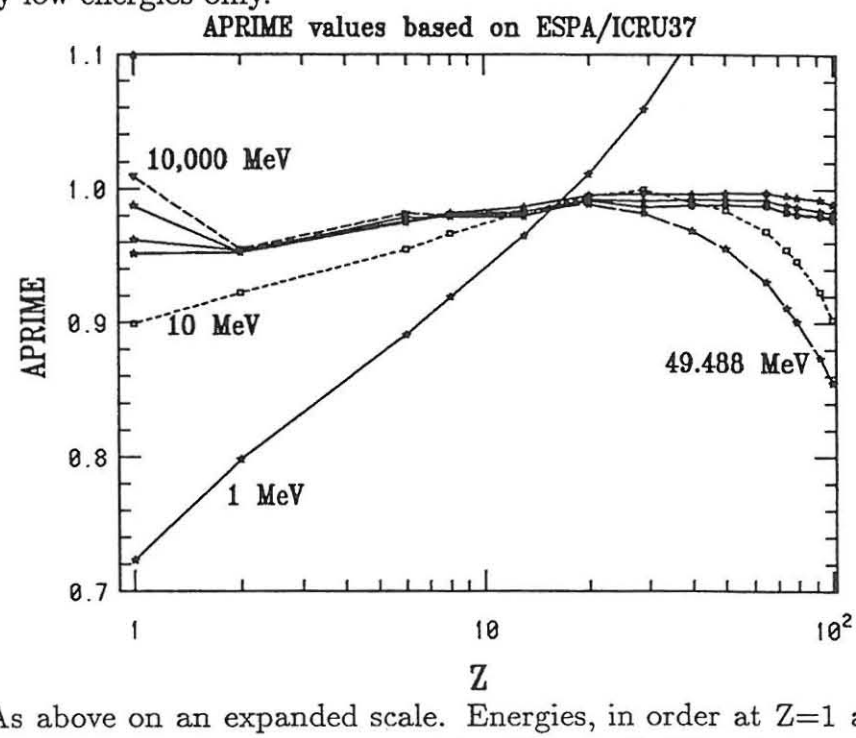

Figure 4: As above on an expanded scale. Energies, in order at Z=1 are 1, 10, 49.488, 50, 100, 1000, 10,000 MeV and at Z=100 are 49.488, 10, 50, 100, 1000, 10,000 MeV. Note the dramatic difference between 49.488 and 50 MeV for high-Z values, which is the result of PEGS4 turning on the relativistic coulomb correction at 50 MeV, which makes a marked improvement for high-Z.

linearly in log Z to produce APRIM(Z,E) values for all elements which reproduced the ICRU 37/NBS radiative stopping powers within 1% (and usually much less) for all energies between 10 keV and 10 GeV. This 1% figure is more accurate than the quoted uncertainties on the NBS radiative stopping powers. Between 1 keV and 10 keV, agreement was still within 1% except for the following elements, which produce slightly low results: B(−2%); F(−1.3%); Li(−4.5%); Ne(−2.0%); Na(−1.5%).

Note that for several of the comparisons for elements with Z > 92, it was necessary to match explicitly the atomic weight, A, used by PEGS4 and ESPA since the default values differed.

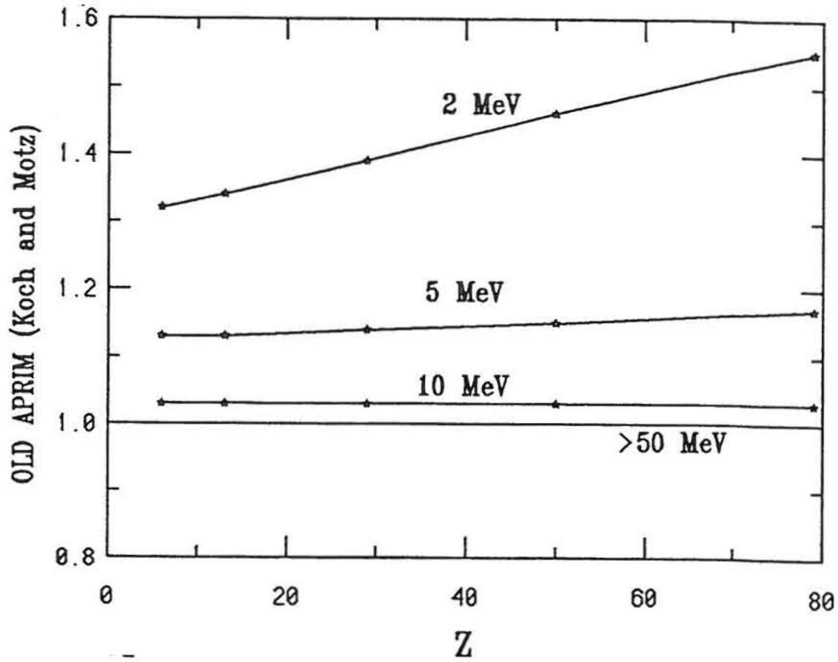

Figure 5: Values of APRIM used in the default PEGS4 system. These were taken from Koch and Motz (according to SLAC-265). Values below 2-MeV are extrapolated linearly in the energy.

Figure 5 shows the Koch and Motz correction factors used in the default version of PEGS4. Several points are worth noting. Since the new values of APRIM are within 5% of unity for all Z above 50 MeV, the old and new values agree within 5%, and usually within 2% for Z > 10. For other energies there are bigger changes. At 10 MeV, it is as much as a 10% decrease. At lower energies, the changes are much larger, as much as a factor of 50 at 1 keV.

For energies above 10 GeV, the modified PEGS4 will use the APRIM at 10 GeV.

5 Errors in the Bremsstrahlung Cross Section for Positrons

In PEGS4 and the EGS4 system, the radiative stopping powers and corresponding bremsstrahlung from electrons and positron are calculated using the same cross sections. According to ICRU Report 37 [3], there is actually considerable difference for low energies and high-Z values. The table gives some representative examples.

Table 1: Ratio of radiative stopping powers for positrons to electrons as given in ICRU Report 37.

Energy MeV	Water	Lead
0.010	0.57	0.11
0.100	0.87	0.24
1.00	0.97	0.47
5.00	0.997	0.70
10.	1.000	0.79
50.	1.000	1.00

In certain situations, this could pose a problem. We have not implemented this generalization, but it could be added to EGS4/PEGS4 without major changes. Note that EGS4 is already one step ahead of ETRAN and the ITS systems where electrons and positrons are treated as identical except for the creation of annihilation photons at the end of a positron's history. EGS *does* carry along the correct collision cross sections and stopping powers for positrons. However, one can run ETRAN with a complete positron data base for handling the case of a positron beam, a clear preference if, for example, one is calculating the bremsstrahlung from a positron beam.

6 Latest Cross Section Values

Seltzer and Berger [6,7] have revised their best estimates of the total cross section since the release of ICRU37. For the total cross section these are mostly minor revisions. The programs ESPB (and EPSTAR) [4] produce radiative stopping powers based on these revised cross sections. We have also generated a data file of APRIM values which produce these cross sections. We compared the radiative stopping powers generated by PEGS4 with this data set to the values from ICRU37 for all elements. For almost all elements the agreement is within 1%, and it is within 2% for all elements except hydrogen. For the sake of a well defined, widely used data set, we therefore intend to use the APRIM values based on ICRU37. However, the second set of APRIM values is available (APRIM_SB.DAT).

7 Some Checks

Aside from the checks for all elements discussed above, we have compared the new radiative stopping powers for water with those in ICRU37 and found agreement within a few parts in 10^4, as expected since both hydrogen and oxygen are part of the APRIM basis set. Note that the comparisons reported here are based on outputs using the PLOT option in PEGS4. The actual data used in EGS may differ slightly because they represent an optimized piece-wise linear fit.

We have also done a check by varying the value of AP and determining the average energy of primary electrons, initially at 10 MeV, after passing through a 1 mm plate of W. We turned off multiple scattering and all secondary electron production. As the value of AP changed from 10 keV, in which case an average of 2 photons were given off while passing through the plate, to 10 MeV, in which case there were no secondary photons given off, the mean energy of the primaries leaving the plate remained constant. This demonstrates that the proper relationship between the differential and integrated cross sections has been maintained.

8 The Distribution Files.

The following files are available from NRC on a PC floppy, and are being included (after March 1989) as part of the EGS4 distribution tape from SLAC.

PEGS4.MOR (PEGS4N.MOR on the SLAC tape)
This is the NRC current version. It therefore includes the upgrade described

patch to subroutine PLOT which we used to create the APRIM files. Finally, it also includes two patches: one to correct an error in calculating the density effect for gases not at NTP (i.e. for GASP non-zero: see SPINIT, error was pointed out by Prof. Kamae in Tokyo, via Hideo Hirayama); the second to correct some errors in SPTOTE(P) when IUNRST=2, 3 or 4 were used in the PLOT or CALL option.

APRIM_37.DAT
This should be assigned to unit 22 when running PEGS for IAPRIM=1.

APRIM_SB.DAT
This uses APRIM values based on the latest Seltzer and Berger evaluations, but is substantially the same (for integral cross sections) as in ESPA.

9 Acknowledgements

We thank Stephen Seltzer of NBS for sending a copy of his PC program EPSTAR which calculates the ICRU 37 density-effect corrections for an arbitrary material. We also wish to thank Hideo Hirayama for useful discussions about corrections for various errors in PEGS4.

Appendix A

Changes Introduced into PEGS4.MOR

```
Differences as of Jan 9,1989, related to new brem cross sections in PEGS

File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
  257   "***EPSTAR      NRCC ADDITION, NOV 1988                              "
  258   "--------------------------------------------------------------------"
  259   REPLACE {;COMIN/EPSTAR/;} WITH
  260      {;INTEGER EPSTFL;CHARACTER*1 EPSTTL(80);INTEGER ZEPST;
  261        COMMON/EPSTAR/EPSTEN(150),EPSTD(150),EPSTFL,EPSTTL,NEPST,IEPST,
  262        NELEPS,ZEPST(20),WEPST(20),IAPRIM,IAPRFL;}
  280   "*** FUNCS                                                           "
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
  247   "*** FUNCS                                                           "
************
************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
  542      PHPAIR,PMCONS,PWLFIN,RAYLEI,RSLTS,THRESH,EPSTAR/;"MODNOV 23,1988"
  543   REAL XP(4),WASAV(20);
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
  510      PHPAIR,PMCONS,PWLFIN,RAYLEI,RSLTS,THRESH/;
  511   REAL XP(4),WASAV(20);
************
************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
  571      EI,ISUB,GASP,IUNRST,IRAYL,AFACT,SK,XO,X1,IEV,CBAR,ISSB,EPSTFL,
  572      IAPRIM;
  573   "                   MOD NOV 23,1988                    ======"
  574   NAMELIST/PWLFNM/EPE,ZTHRE,ZEPE,NIPE,NALE,EPG,ZTHRG,ZEPG,NIPG,NALG,
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
  539      EI,ISUB,GASP,IUNRST,IRAYL,AFACT,SK,XO,X1,IEV,CBAR,ISSB;
  540   NAMELIST/PWLFNM/EPE,ZTHRE,ZEPE,NIPE,NALE,EPG,ZTHRG,ZEPG,NIPG,NALG,
************
************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
  942         PHPAIR,PMCONS,PWLFIN,RADLEN,RAYLEI,SPCOMM,RSLTS,THRESH,EPSTAR/;
  943   "                               MOD NOV 22 1988          ======"
  944
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
  908         PHPAIR,PMCONS,PWLFIN,RADLEN,RAYLEI,SPCOMM,RSLTS,THRESH/;
  909
************
************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
 1187
 1188   "DATA FOR EPSTAR"
 1189   DATA EPSTFL/0/,IEPST/1/,IAPRIM/0/,IAPRFL/0/;
 1190
 1191   END; "END OF BLOCK DATA"
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
 1152   END; "END OF BLOCK DATA"
************
************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
 1537   COMIN/BREMPR,MIXDAT,RAYLEI,RSLTS,THRESH,MOLVAR,EPSTAR/;
```

```
 1538   "          NRC MOD DEC 2,1988                    ======"
 1539   :INT:FORMAT(1X,14I5);
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
 1498   COMIN/BREMPR,MIXDAT,RAYLEI,RSLTS,THRESH,MOLVAR/;
 1499   :INT:FORMAT(1X,14I5);
*************
*************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
 1545   IF(GASP.NE.0.0) [$ECHOWRITE(IP,:FMT2:) MTYP,RHO,NE,GASP,
 1546   IUNRST,EPSTFL,IAPRIM; "  NRC MODS DEC 2 1988"
 1547   :FMT2: FORMAT(1X,4A1,',RHO=',1PE11.4,',NE=',I2,',GASP=',
 1548     1PE11.4,', IUNRST=',I1,', EPSTFL=',I1,', IAPRIM=',I1);] "GASES"
 1549   "  NRC MOD  =========================================="
 1550   ELSE [$ECHOWRITE(IP,:FMT3:) MTYP,RHO,NE,IUNRST,EPSTFL,IAPRIM;
 1551   "  NRC MODS                                ===================="
 1552   :FMT3: FORMAT(1X,4A1,',RHO=',1PE11.4,',NE=',I2,',IUNRST=',I1,
 1553   ', EPSTFL=',I1,', IAPRIM=',I1);] "NRC MODS DEC 1988"
 1554   DO IE=1,NE [
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8
 1505   IF(GASP.NE.0.0) [$ECHOWRITE(IP,:FMT2:) MTYP,RHO,NE,GASP;
 1506   :FMT2: FORMAT(1X,4A1,',RHO=',1PE11.4,',NE=',I2,',GASP=',
 1507     1PE11.4);] "GASES"
 1508   ELSE [$ECHOWRITE(IP,:FMT3:) MTYP,RHO,NE;
 1509   :FMT3: FORMAT(1X,4A1,',RHO=',1PE11.4,',NE=',I2);]
 1510   DO IE=1,NE [
*************
*************
*************       The FOLLOWING IS THE NEW FUNCTION APRIM
*************
File SYS$SYSDEVICE:   NEW_PEGS4.MOR;32
 2816
 2817   "      EMPIRICAL CORRECTION FACTOR TO BREMS CROSS SECTION             "
 2818
 2819   " This version can be switched to use different values:               "
 2820   "    IAPRIM = 0  equivalent to old PEGS4 (default)                     "
 2821   "             1  reads in values from unit 22                          "
 2822   "             2  sets APRIM to 1.0                                     "
 2823   " Future changes can be accommodated by reading in                     "
 2824   " different data on unit 22 and if necessary changing the array sizes: "
 2825
 2826   REPLACE {$NAPRE} WITH {115} " Maximum number of energies ( > 18 )     "
 2827   REPLACE {$NAPRZ} WITH {14}  " Maximum number of elements ( > 5 )      "
 2828
 2829   REPLACE {$NAPR1} WITH {{COMPUTE $NAPRE - 18}}
 2830   REPLACE {$NAPR2} WITH {{COMPUTE $NAPRZ - 5}}
 2831   REPLACE {$NAPR3} WITH {{COMPUTE $NAPRE * $NAPR2}}
 2832   ;COMIN/DERCON,EPSTAR/; "NRC CHANGE NOV 88"
 2833   REAL APRIMD($NAPRE,$NAPRZ),EPRIM($NAPRE),ZPRIM($NAPRZ),APRIMZ($NAPRE);
 2834   DATA APRIMD/
 2835   1.32,1.26,1.18,1.13,1.09,1.07,1.05,1.04,1.03,1.02,8*1.0,$NAPR1*0.0,
 2836   1.34,1.27,1.19,1.13,1.09,1.07,1.05,1.04,1.03,1.02,8*1.0,$NAPR1*0.0,
 2837   1.39,1.30,1.21,1.14,1.10,1.07,1.05,1.04,1.03,1.02,0.994,
 2838    2*0.991,0.990,2*0.989,2*0.988,$NAPR1*0.0,
 2839   1.46,1.34,1.23,1.15,1.11,1.08, 1.06,1.05,1.03,1.02,0.989,
 2840    0.973,0.971,0.969,0.967,0.965,2*0.963,$NAPR1*0.0,
 2841   1.55,1.40,1.26,1.17,1.12,1.09,1.07,1.05,1.03,1.02,0.955,0.935,
 2842    0.930,0.925,0.920,0.915,2*0.911,$NAPR1*0.0,
 2843   $NAPR3*0.0/,
 2844   EPRIM /
 2845   2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,21.,31.,41.,51.,61.,71.,81.,91.,
 2846   $NAPR1*0.0/,
 2847   ZPRIM /6.,13.,29.,50.,79.,$NAPR2*0.0/,
 2848   IAPRFL /0/;
 2849   IF (IAPRIM.EQ.0) [ " PEGS4 default APRIM"
```

```
    IF(IAPRFL = 0)[IAPRFL=1;OUTPUT;('0IAPRIM=0, i.e. uses KOCH AND MOTZ',
    ' empirical corrections to brem cross section'/);]
    IF (E.GE.50) [ APRIM=1.; ]
    ELSE [ " INTERPOLATE APRIM OVER Z "
        EM=E/RM;
        DO IE=1,18[
           APRIMZ(IE)=
           AINTP(Z,ZPRIM,5,APRIMD(IE,1),$NAPRE,.FALSE.,.FALSE.);
           ] " Z INTERPOLATION IS NOW COMPLETE. NOW DO ENERGY "
        APRIM=AINTP(EM,EPRIM,18,APRIMZ,1,.FALSE.,.FALSE.);
        ]
    ]
ELSEIF (IAPRIM.EQ.1) [
    IF (IAPRFL.EQ.0) [ " read in data from APRIME.DATA"
        OUTPUT;('0IAPRIM=1, i.e. uses NRC(based on NIST/ICRU)',
       ' corrections to brem cross section'/);
        READ(22,*) NAPRZ, NAPRE;
        IF (NAPRZ.GT.$NAPRZ) [
            OUTPUT; (//,' TOO MANY ELEMENTS FOR APRIME INTERPOLATION:',
            /,'    CHANGE $NAPRZ AND RECOMPILE PEGS'); STOP;]
        IF (NAPRE.GT.$NAPRE) [
            OUTPUT; (//,' TOO MANY ENERGIES FOR APRIME INTERPOLATION:',
            /,'    CHANGE $NAPRE AND RECOMPILE PEGS'); STOP;]
        READ(22,*) (EPRIM(IE),IE=1,NAPRE);
        DO IE=1,NAPRE [ EPRIM(IE)=1.+EPRIM(IE)/RM; ]
        DO IZ=1,NAPRZ [READ(22,*)ZPRIM(IZ),(APRIMD(IE,IZ),IE=1,NAPRE);]
        IAPRFL=1;
        ]
    EM=E/RM;
    DO IE=1,NAPRE [ " INTERPOLATE APRIM OVER LOG(Z)                 "
        APRIMZ(IE)=
        AINTP(Z,ZPRIM,NAPRZ,APRIMD(IE,1),$NAPRE,.TRUE.,.FALSE.);
        ]          " NOW DO ENERGY INTERPOLATION     "
    APRIM=AINTP(EM,EPRIM,NAPRE,APRIMZ,1,.FALSE.,.FALSE.);
    ]
ELSEIF (IAPRIM.EQ.2) [
        IF(IAPRFL = 0)[IAPRFL=1;
        OUTPUT;('0IAPRIM = 2, i.e. uses NO corrections to brem',
        ' cross section'/);]
        APRIM=1.0]
ELSE [ OUTPUT IAPRIM; (//,' ILLEGAL VALUE FOR IAPRIM: ',I4); STOP; ]
RETURN;
******
File SYS$SYSDEVICE:   OLD_PEGS4.MOR;8

COMIN/DERCON/;
"     EMPIRICAL CORRECTION FACTOR TO BREMS CROSS SECTION                "
REAL APRIMD(18,5),EPRIM(18),ZPRIM(5),APRIMZ(18);
DATA APRIMD/1.32,1.26,1.18,1.13,1.09,1.07,1.05,1.04,1.03,
 1.02,8*1.0,1.34,1.27,1.19,1.13,1.09,1.07,1.05,1.04,1.03,1.02,
 8*1.0,1.39,1.30,1.21,1.14,1.10,1.07,1.05,1.04,1.03,1.02,0.994,
 2*0.991,0.990,2*0.989,2*0.988,1.46,1.34,1.23,1.15,1.11,1.08,
 1.06,1.05,1.03,1.02,0.989,0.973,0.971,0.969,0.967,0.965,2*0.963,
 1.55,1.40,1.26,1.17,1.12,1.09,1.07,1.05,1.03,1.02,0.955,0.935,
0.930,0.925,0.920,0.915,2*0.911/,EPRIM/2.,3.,4.,5.,6.,7.,8.,
9.,10.,11.,21.,31.,41.,51.,61.,71.,81.,91./,ZPRIM/6.,13.,
29.,50.,79./;
IF (E.GE.50) [APRIM=1.; ]
ELSE [EM=E/RM;
"     INTERPOLATE APRIM OVER Z.                                         "
DO IE=1,18[
APRIMZ(IE)=AINTP(Z,ZPRIM,5,APRIMD(IE,1),18,.FALSE.,.FALSE.);]
"     Z INTERPOLATION IS NOW COMPLETE. NOW DO ENERGY INTERPOLATION      "
APRIM=AINTP(EM,EPRIM,18,APRIMZ,1,.FALSE.,.FALSE.);]
RETURN;
************
```

Appendix B

Listing of APRIM Data File

The following file is read as unit 22 when IAPRIM=1 is defined. The format is:

NAPRZ, NAPRE	The number of elements and energies to be read in.
EPRIM(IE), IE=1,NAPRE	The energy grid for all elements.
For each element:	
Z	(real) the Z value for this element:
APRIMD(IE,IZ), IE=1,NAPRE:	The values of APRIM for this element as a function of energy.

Note that the highest energy has been added by hand and APRIM for the extra energy has been set equal to the next highest so that the extrapolation is constant at the highest value.

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14 115
1.0000E-03,1.2500E-03,1.5000E-03,1.7500E-03,2.0000E-03,2.5000E-03,3.0000E-03,
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6.0000E-02,7.0000E-02,8.0000E-02,9.0000E-02,1.0000E-01,1.2500E-01,1.5000E-01,
1.7500E-01,2.0000E-01,2.5000E-01,3.0000E-01,3.5000E-01,4.0000E-01,4.5000E-01,
5.0000E-01,5.5000E-01,6.0000E-01,7.0000E-01,8.0000E-01,9.0000E-01,1.0000E+00,
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9.0000E+00,1.0000E+01,1.2500E+01,1.5000E+01,1.7500E+01,2.0000E+01,2.5000E+01,
3.0000E+01,3.5000E+01,4.0000E+01,4.5000E+01,4.9488E+01,5.0000E+01,5.5000E+01,
6.0000E+01,7.0000E+01,8.0000E+01,9.0000E+01,1.0000E+02,1.2500E+02,1.5000E+02,
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9.0000E+03,1.0000E+04,1.25e+4
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